REF

SOME HYDROGEOLOGIC CONSIDERATIONS IN LANDFILL SITE EVALUATION

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THE ONTARIO MINISTRY OF THE ENVIRONMENT

Water Resources Branch

Hydrology and Monitoring Section

SOME HYDROGEOLOGIC CONSIDERATIONS IN LANDFILL SITE EVALUATION

by

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July 1977

Toronto

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SOME HYDROGEOLOGIC CONSIDERATIONS IN LANDFILL SITE EVALUATION

INTRODUCTION

This paper has been prepared to assist Regional personnel in appraising the hydrogeology of existing and proposed landfill sites. It is assumed that the reader has an understanding of basic hydrogeology.

Discussed in this paper are the hydrogeologic factors which affect the production and the migration of contaminants from landfills and some of the procedures which are used in evaluating the significance of these factors at particular sites. Also included are discussions of some of the engineering techniques which are used to control contamination where natural safeguards in the environment are not adequate.

Each landfill site represents a unique hydrogeologic environment and its design must be suited to that particular environment. Therefore, few Province-wide rules or guidelines can be established and for the most part, sites must be evaluated on an individual basis. An outline of some of the data which should be considered in a site evaluation is presented in Appendix A.

Most landfill site evaluations will involve a judgement of how the landfill will affect the quality (and in some cases the quantity) of the ground and surface waters at some point of concern away from the disposal site. This point may, for example, be the property line or a nearby water well. To this end, an estimate may be required of the quantity of leachate which will be produced by the landfill, its quality, and the amount of attenuation this leachate will undergo as it moves away from the disposal site.

The quantity of leachate produced may be estimated as discussed in Appendix B. An estimate of the quality of the leachate which will be produced might best be obtained from analyses of refuse leachate from other landfills which have received similar types of wastes. Table 1 shows the range in the concentration of various components in refuse leachate from different landfills. It is apparent from Table 1 that refuse leachate is extremely variable in composition.

Attenuation is dependent upon:

1. Bacterial decomposition of the leachate;
2. Dilution of the leachate;
3. Chemical and physical interactions in the leachate and between the leachate and the surrounding soils.

TABLE 1

Summary of Leachate Characteristics*
From Municipal Solid Wastes

Components	Range of all Values (mg/l excepting pH)
Alkalinity ($CaCO_3$)	0-20850
BOD (5 day)	9-54610
Calcium	5-4080
COD	0-89520
Copper	0-9.9
Chloride (Cl^-)	34-2800
Hardness ($CaCO_3$)	0-22800
Iron-Total	0.2-5500
Lead	0-5.0
Magnesium	16.5-15600
Manganese	.06-1400
Nitrogen-NH_3	0-1106
Nitrogen-Kjeldahl	0-1416
Nitrogen-NO_3	0-1300
Potassium	2.8-3770
Sodium	0-7700
Sulfate ($SO_4=$)	1-1826
TDS	0-42276
TSS	6-2685
Total Phosphate	0-154
Zinc	0-1000
pH	3.7-8.5 +

* *Table taken from Garland, George A, and D. C. Mosher, 1975, Leachate effects of improper land disposal, Waste Age, March 1975, Page 42-48.*

+ *Excluding incinerator residue.*

These in turn depend to a large extent on the hydrogeology of the disposal site, i.e., the velocity at which the leachate moves, the path it follows, and the material it traverses in moving from the disposal site to the point of concern.

It is not as yet possible to measure all of the pertinent hydrogeologic parameters which determine the suitability of a proposed disposal site. However, our understanding of these parameters is sufficient to allow a qualitative judgement of the effect of waste disposal in various hydrogeologic environments and thereby take measures to ensure safe disposal.

HYDROGEOLOGIC FACTORS INFLUENCING LEACHATE MIGRATION AND ATTENUATION

Leachate Production and Migration

Leachate will be produced at all landfills in Ontario because climatic conditions in the Province do not permit the complete elimination of surface infiltration (Appendix B). Refuse leachate is produced by water in a landfill mobilizing contaminants from the buried refuse. Water may enter the landfill from the surface, through the sides or base, or be buried with the refuse or cover materials. The leachate thus produced must eventually leave the landfill as surface runoff on the ground surface, as ground water in the sub-surface, or through an engineered facility.

The three principal hydrogeologic factors that control the movement of leachate with the ground water are:

1) The permeability* of the refuse and the earth material(s) surrounding the landfill.

2) The position of the landfill site with respect to local or regional ground-water flow systems.

3) The position of the refuse with respect to the top of the zone of saturation.

Permeability of the Earth Material(s) Surrounding the Landfill

In most cases the permeability of the earth material(s) in and around a landfill site will be the most important hydrogeologic factor influencing the suitability of the site. It is difficult to quantify a relationship between permeability and the movement of contaminants; however, based on the many case histories in the literature, the following generalities may be reasonable.

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* *The term "permeability" is used in place of the more correct term "hydraulic conductivity".*

The concentration of dissolved solids in the ground water moving from a landfill in earth material(s) with low permeability (on the order of 10^{-6} cm./sec. or less) is generally reduced to acceptable levels within a few tens of feet from the disposal site. Where the earth material(s) surrounding the landfill site have low permeability, contamination if any, generally occurs at the surface and is associated with springs on the margins of the landfill and/or streams immediately adjacent to the landfill.

Significant concentrations of contaminants may move many hundreds or thousands of feet with the ground water from disposal sites in earth materials with high permeability (on the order of 10^{-2} cm./sec. or greater) or in most fractured rocks. Waste disposal sites in such fractured rocks are of particular concern. Ground water flow through these rocks is very difficult to describe or predict, even with extensive investigation. In addition, the ability of fractured rocks to attenuate those contaminants which move through them is quite low.

It is often necessary to design leachate collection and disposal facilities into landfills located in permeable sand and gravel deposits and in fractured rocks.

The evaluation of landfill sites in earth materials with intermediate permeability is particularly difficult. Knowledge of contaminant attenuation in the sub-surface is not well enough developed to predict contaminant travel distances with certainty and unless the permeability of the materials around a site can be easily classified as obviously "high" or "low", the question of whether contaminants are likely to move tens of hundreds of feet must rely for the most part on personal judgement. Studies of methods of quantifying contaminant movement in the sub-surface are being conducted but have not as yet been used to evaluate proposed landfill sites. Under these circumstances, factors other than permeability must assume a relatively greater importance.

Large permeability contrasts between adjacent units are common in geologic materials and such contrasts may have a critical effect on both the quantity and the direction of leachate flow from a waste disposal site. For example, a thin bed of sand will not only transmit far more water than a much thicker clay unit, but will usually amplify the horizontal component of the ground-water flow vector along the axis of the sand bed. In designing landfill sites in bedded deposits with a wide range of permeabilities, it will sometimes be possible to blanket the more permeable materials with a cover of less permeable material and thereby confine the leachate to the site or to slow its egress.

It will often be necessary to obtain a more accurate estimate of the permeability of selected hydrogeologic units at the site than can be obtained from a surface examination. This may be done by field and/or laboratory procedures and is generally co-ordinated with a soils boring program.

The Position of the Landfill Site With Respect to Local or Regional Ground Water Flow Systems

To evaluate the environmental effect of landfill and to design a leachate monitoring system (Appendix C), some understanding of the position of the landfill within the ground-water flow system is essential. The configuration of the ground-water flow system in the immediate vicinity of the site will often be the most important control on leachate movement and where this configuration is critical to the landfill design, assumptions should be verified by measurements of the vertical and horizontal components of the ground-water flow vector at the site.

In ground-water discharge areas, the sub-surface path through which the leachate travels is usually short and the area of discharge for the leachate is often obvious and easily confirmed through the use of water-level monitoring points or piezometers. Leachate will remain close to the ground surface in discharge areas and practical means may be available to recover all or part of this leachate, if this should prove necessary.

The most common problems which arise from landfills in discharge areas are associated with the contamination of surface waters, where steps to control leachate egress are not taken.

In ground-water recharge areas there is a downward component to the ground-water flow vector. If the materials through which the leachate moves have high permeabilities, it may be necessary to predict the potential distribution of the contaminants in the subsurface over a considerable distance, as a part of the site evaluation and monitoring program.

In ground-water recharge areas, because contaminants may move to depth, the potential for uncontrollable ground-water contamination is greater than in ground-water discharge areas, and more investigation of the ground-water flow path is required.

The Position of the Refuse With Respect to the Top of the Zone of Saturation

Regulation 824* (Section 10(1)5) under the EP Act requires that waste be placed sufficiently above, or isolated from, the maximum water table to prevent impairment of the ground water in aquifers or contamination of potable water supplies.

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* *This Regulation is currently under revision.*

Circumstances under which disposal below the water table could have an adverse affect on the disposal operation can be described as follows:

1) In hydrogeologic environments, where ground water moves through refuse buried below the water table and produces unacceptable amounts of leachate (Appendix D).

2) In hydrologic environments where the attenuation that the leachate undergoes within the vadose zone is necessary to protect the environment. (Note - there is little or no evidence that attenuation per foot of travel is significantly greater in the vadose zone than in the zone of saturation. Therefore the distance the refuse is placed above the zone of saturation may be relatively unimportant to alternation.

3) Odiferous gases may be produced from refuse which is deposited in standing water. Standing water is more likely to be present in landfill excavations which extend below the water table than in those which do not.

4) Wet or muddy conditions are more likely to be encountered in landfills which intersect the water table than in those which do not. Operational difficulties in moving machinery and in covering refuse are amplified under such conditions. This leads to poor housekeeping and unsightly landfills.

Where these adverse effects are either absent or insignificant, or have been dealt with in a manner which is satisfactory to the Ministry, a requirement that the landfill be above the water table is not realistic. For example, the position of the water table would seldom be an important consideration at a landfill site in a clay pit.

Circumstances under which disposal above the water table could have an adverse affect on the disposal operation can be described as follows:

1) Leachate collection may be more difficult to accomplish. Above the water table, leachate must be directed to the drains by a barrier (liner) with low permeability. Below the water table, this may be accomplished hydraulically.

2) Gas migration problems are more common in landfills bounded by unsaturated earth materials. (Appendix E).

Strict adherence to a requirement that refuse be buried above the top of the zone of saturation may lead to the selection of disposal sites in hydrogeologic environments which, from the standpoint of the permeability of the earth materials and the position of the site in the ground-water flow system, are least suitable. In Ontario, deep water tables are often associated with earth materials having relatively high permeabilities which are located in upland-recharge areas. Conversely, shallow water tables are often associated with ground-water discharge areas and materials with low permeability. The disadvantages and advantages of waste disposal under these conditions have been discussed.

Other considerations relevant to the position of the water table and waste disposal operations are:

1) There is commonly a vertical component to the ground-water flow vector and therefore, only under certain conditions, will the elevation of water in wells reflect the elevation of the top of the zone of saturation. Any difference between the two elevations will depend on:

   a) The magnitude of the vertical component of the ground-water flow vector.

   b) The distance that the well penetrates below the top of the zone of saturation.

   c) The permeability of the units between the top of the zone of saturation and that part of the well open to the aquifer.

2) An excavation in material with low permeability (for example a clay pit) may remain dry or nearly dry during the summer despite the fact that its base is far below the top of the zone of saturation. This occurs because ground water does not move into the excavation as rapidly as it is removed by evaporation. However, during the winter this excavation may fill with water.

3) The climate of Ontario is such that the following generalities can usually be applied.

   a) in areas where the surficial materials have low permeability ($<10^{-6}$ cm./sec.), the top of the zone of saturation will often be within five feet and almost always within fifteen feet of the ground surface.

   b) in areas of low relief, the top of the zone of saturation will generally be within fifteen feet of the ground surface.

c) in areas where the top of the zone of saturation is more than 20 feet from the ground surface, both the local relief and the permeability of the materials involved will usually be high.

An exception to these generalities occurs when surficial materials with low permeability are underdrained by a deeper layer of materials with much higher permeability. Conditions such as this are common in the Oak Ridges Moraine north of Toronto.

AREAS IN WHICH THE ROCKS HAVE VERY LOW TRANSMISSIVITIES

Many of the igneous and metamorphic rocks on the Precambrian Shield in Ontario have very low transmissivities because they have few fractures, and those fractures that are present are often closed or filled near the rock surface with fine-textured or organic sediments. Under these conditions ground-water movement will be controlled to a large degree by the orientation of the fractures or the configuration of the bedrock surface. Measurements of the vertical and horizontal component of the ground-water flow vectors will be of limited value in predicting flow directions because the water will channel along the fractures. The normal upland-recharge/lowland-discharge relationship which we apply to other terrains comprised of more permeable materials may be misleading. Where the transmissivities of the rocks are very low, swamps and lakes, will often be perched in bedrock basins well above the regional water table and will be maintained almost solely by precipitation and surface runoff.

The specific yield of fractured rocks is quite low and the velocity[1] of the ground water moving through the fractures is proportionally higher. This rapid movement combined with the low capacity of these rocks for contaminant attenuation (small surface area) will favour the rapid spread of contaminants from disposal sites located in such rocks.

Where conditions of low transmissivity exist, lowland swamp areas may be the most favourable environments for waste disposal sites. Such sites would take advantage of the surrounding organic materials to attenuate some of the dissolved solids in the leachate. Providing that the leachate is not permitted to leave the area through surface streams, the low ground-water gradients and correspondingly slow ground-water velocities through the swamp sediments may allow sufficient time for the biodegradable materials in the leachate to decompose.

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[1] $V = \frac{KI}{Sy}$

where: V = *velocity at which the ground water moves*
I = *the hydraulic gradient*
Sy = *the specific yield (effective porosity) of the materials through which the water moves*
K = *the permeability (hydraulic conductivity) of the materials through which the water moves*

In upland areas, ground-water gradients are likely to be high. Unless the fracture system in the rocks can be defined or the permeability of the rocks proven to be sufficiently low, there would be the potential for rapid and unpredictable contaminant movement away from the disposal site.

SURFACE WATER CONTAMINATION

Most instances of surface-water contamination from landfills occur in two distinct hydrogeologic environments.

1. Landfills on valley sides or in gulleys;

2. Landfills in flat, swampy or marshy areas immediately adjacent to streams.

Landfills on valley sides or in gulleys may receive water both from springs and from up-slope runoff. In these environments, ground-water levels may be close to the surface and if springs are not initially present, they are often encountered during the excavation of the site. Leachate on leaving the landfill in these environments, will tend to remain on the surface and move rapidly to the nearest stream with only a minimum of natural treatment en route. Contamination problems may be reduced or avoided by diverting surface water around or beneath the landfill, by sealing springs beneath the landfill, or by constructing underdrains to carry this water away before it contacts the refuse.

Landfills in marshy or swampy areas next to streams rely on the materials between the landfill and the stream to reduce the dissolved solids content of the leachate to acceptable levels before it reaches the stream. Problems with surface-water contamination will develop when the distance between the stream and the landfill is not great enough, or the volume of leachate is too great to allow adequate reduction of the contaminants to take place. Where this situation occurs, the amount of leachate discharged to the stream may be reduced by:

1) Decreasing the amount of infiltration through the landfill surface.

2) Constructing perimeter drains around the landfill and collecting all or a part of the leachate.

LEACHATE CONTROL FACILITIES

Leachate control facilities are often proposed at sites where natural conditions are not believed adequate to ensure safe disposal. Such facilities may also be incorporated

into a landfill design as a backup system or as part of a contingency plan where there is some doubt as to the adequacy of natural conditions to provide environmental protection.

Leachate control facilities may consist of natural or artificial liners underneath leachate collection tiles which lead to leachate treatment systems. These types of facilities have been used on a number of landfills but as yet quantitative data are not available to demonstrate their effectiveness.

Purge wells, which have been used successfully for years to dewater excavations and leachate recirculation (Appendix F) systems have also been proposed to control and collect leachate but such systems are also relatively new and have not been fully tested on landfills.

Advantages to the use of leachate control facilities are:

a) To allow the use of otherwise unsuitable disposal sites close to the source of refuse production and therefore save transportation costs.

b) To enable the rehabilitation of "waste" areas such as worked-out gravel pits and quarries and allow these areas to be returned to a higher land use.

Disadvantages to the use of leachate control facilities are:

a) Such facilities are not fully field tested and there are questions as to their reliability. (e.g. the "life" of a plastic liner is not known). As an aside, it should be noted that the testing of these facilities may best be accomplished by using them at landfill sites and monitoring their effectiveness over long time periods.

b) For some contaminants, leachate collection and treatment merely involves displacing the contaminant from a ground-water to a surface-water system. These are generally the same contaminants that are not attenuated in the sub surface.

c) The cost of these facilities is substantial and their installation requires a high degree of technical expertise.

d) Legal and administrative considerations are involved in permitting landfills with leachate control facilities. These include arrangements for guaranteed maintenance until the landfill has stabilized (Appendix F) and meeting the costs involved in construction and maintenance. The long biologic life of a landfill is of special concern.

OTHER CONSIDERATIONS RELATED TO HYDROGEOLOGY

There are a number of other factors in landfill site design directly related to the hydrogeology of the site which should be addressed in the evaluation of a site.

Present and anticipated land and water use in an area will affect hydrogeologic decisions concerning the suitability of the site and the appropriate design for the landfill.

A quantitative estimate of the available ground water in the area may be necessary. This, combined with information from local officials on anticipated growth and potential use of the ground water, will give an indication of the importance of protecting this resource. The presence or absence of alternate sources of water will affect the value of the ground-water resource.

The future use of the landfill site may determine aspects of the landfill design and should be discussed with those responsible for planning. For example, irrigation accompanying the development of a golf course over a completed landfill may increase infiltration and therefore leachate production. This may not be acceptable at a landfill where minimum leachate production is desirable. Small surface springs of leachate may be acceptable around a small rural landfill but not acceptable at a landfill in a residential area or one which is to be converted into a recreational facility.

In addition to the numerous problems associated with construction on the landfill itself, gases are produced by a landfill (Appendix E) which may affect adjacent areas.

Questions which should also be considered are:

1) Will present ground-water gradients be modified by future development and if so, how will these changes affect hydrologic conditions of the landfill?

2) If mistakes or errors are made in the construction of the landfill and effluent from the landfill contaminates water supplies, are there other sources of water available? What will the consequences be if some aspects of the design of the landfill fail? Is a reasonable contingency plan possible?

3) Economics often favour the expansion of existing sites over the development of new sites. Will there be pressure in the future to this end and if so can a site be expanded?

4) Are there other waste discharges in this area and if so can an estimate of the cumulative effect of these discharges be made?

5) Can the responsibility for the maintenance of the site and for its future environmental effects be assigned for tens of years (Appendix F) or until the landfill stabilizes?

SUMMARY

All landfills in Ontario will produce contaminants and will have some effect on the environment.

In general, landfilling in low permeability materials can be safely accomplished if leachate springs and the resulting surface water contamination problems are controlled.

Safe landfilling in high permeability materials is somewhat more difficult as it depends on an understanding of the ground-water flow system sufficient to ensure that the leachate will be adequately attenuated before it reaches a point of water use. If natural attenuation is not possible, an engineered collection and treatment facility may be required.

Collection and treatment facilities could theoretically be used at any site to control leachate. However, these facilities are unproven, difficult to install and operate, are expensive, and require guarantees of maintenance for tens of years. Landfills in which the leachate is handled by natural processes without maintenance are much preferred.

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APPENDIX A

EVALUATION OF SITE STUDIES

A report on a proposed landfill could include answers to the following questions. However, not all of these questions will be pertinent at all landfill sites.

1. Have the vertical and horizontal components of the ground-water flow vector been considered? Do the ground-water potentials plotted in plan and on stratigraphic cross-sections present a rational picture of ground-water flow which fits in to the regional ground-water flow system? Is this compatible with the permeability of the geologic units? Does the geology of the site fit into the regional pattern?

2. If it is necessary to collect the leachate, how much of the leachate which will be produced will be intercepted by the collection system? How much surface infiltration is expected? If this is to be controlled by the cover material, what provisions have been made for maintaining this cover?

3. What were the procedures used to install the piezometers and well points? Were their seals checked and have they stabilized? Are they functioning properly?

4. What procedures were used to obtain the water quality samples? Were the sampling points cleaned before the samples were taken? What is the time lag in these installations?

5. What procedures were used to obtain the soil samples? Were they undisturbed and relatively reliable? Who supervised the field operations?

6. Can a simple water balance be made by using estimates of precipitation, infiltration and streamflow, etc.? If such calculations can be made by using more than one method, are the results of the various methods comparable?

7. Has a monitoring system been designed in accordance with the ground-water flow system? When, and at what concentrations are the indicator parameters expected to reach the monitoring points?

8. Has a contingency plan been agreed upon, and is this plan compatible with the site hydrogeology?

9. Has a discussion of the possible effect of the landfill on the surrounding ground and surface waters been included in the report? Is this based on quantitative or qualitative information? Is an accurate estimate of the landfill's effect necessary or is there a significant safety factor present?

10. What is the present water use in the vicinity of the site? Are potential water uses likely to be important?

APPENDIX B

LEACHATE PRODUCTION AND LANDFILL COVER

In a humid climate, some part of the precipitation falling on the surface of a landfill will infiltrate to form leachate. Where the amount of leachate produced from a landfill will bear upon its suitability, a quantitative estimate of this infiltration must be made. Leachate may, in some circumstances, (Appendix D) be produced by ground water moving through the refuse. Quantitative estimates of leachate produced by this mechanism can be made by standard hydrogeologic techniques and will not be discussed further.

Precipitation is dissipated as evapotranspiration, runoff, and infiltration. If precipitation, evapotranspiration and runoff can be quantified, then an estimate of the amount of infiltration can be made.

Most landfill covers are designed to be relatively maintenance-free, with a stable surface that will not be eroded by surface runoff to expose buried refuse. For the present, we will therefore assume that runoff from a landfill will be zero, and that precipitation minus evapotranspiration is equal to the amount of water which infiltrates through the landfill surface.

Maps showing precipitation, evapotranspiration and water surplus[1] data for southern Ontario are presented by Brown et al (1974, p. 32, 42, 43). Similar data are presented for northern Ontario by Chapman and Thomas (1968). According to Brown (1974, p. 31), the annual precipitation in southern Ontario ranges from 26 to 40 inches, the mean value of the annual actual evapotranspiration (p. 41) is 21 inches and the average annual water surplus (p. 41) is 9 to 17 inches per year. Assuming negligible runoff from a landfill, most of this water surplus in the area, as estimated from Brown et al (1974) can be used as an approximation of the minimum amount of water which will infiltrate through a well constructed landfill cover.

The use of this method to estimate the amount of infiltration into a landfill is subject to some valid criticism, particularly with respect to the assumption of zero runoff. However, it agrees in general with experiments conducted by Professor L. R. Webber of the University of Guelph (personal communication), with preliminary results obtained from a study using lysimeters buried in landfills (Hydrology Consultants Limited 1976, p. 3) and with results obtained in a study of landfills in Illinois (Hughes et al 1971, p. 40).

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1 *"Precipitation in excess of that needed to saturate the soil is considered as a surplus, which runs off and is available as surface water or percolates to the water table" (Brown et al 1974, p. 41).*

In a particular case, evidence may be presented to demonstrate that runoff or infiltration will differ from the amounts suggested. This evidence might be based on considerations of the slope and the configuration of the landfill surface, the vegetation on the landfill, the permeability of the landfill cover, and the distance across the surface of the landfill that the runoff water must move to reach the edge of the landfill. Such estimates depend heavily on empirical data and the individual's experience in a particular area. The equations which are used were, for the most part, developed as a part of erosion, irrigation and flood control measures rather than as a tool to estimate infiltration. It is suggested therefore that an estimate that varies significantly from that obtained from the data in Brown et al (1974) be very carefully reviewed and if necessary be substantiated by measurements made in lysimeters or other facilities on the landfill itself.

According to Professor Webber, (personal communication) to be maintenance free, the cover of a landfill in Ontario should have the following general characteristics:

a) A smoothly graded and compacted surface with at least 12 inches of final cover to support vegetation.

b) A dense sod vegetation which may be mowed or left in pasture. Soils ranging from a sandy loam to a clay loam would be required to support such a cover.

c) A slope between 5% and 16%. Ponding is likely to occur on slopes less than 5% and erosion on slopes greater than 16%. Slopes greater than 50% cannot be mowed and periodic mowing is beneficial in that it increases evapotranspiration and will improve the appearance of the landfill.

Where conditions dictate, special techniques (i.e. ditches lined with concrete) have been employed to achieve less infiltration. However, these techniques should be evaluated on a site-by-site basis.

A few additional points should be considered:

1. Ditches, drains, etc. can be used to increase runoff without erosion, however, most of these facilities will require maintenance.

2. Final construction and grading of a landfill cover will probably not be possible until the landfill has been completed and most of the settlement has taken place. It has been estimated (U.S. Environmental Protection Agency, 1974, p. 16) that 90% of the ultimate settlement will occur in the first five years after filling.

3. Estimates of the amount of water which will infiltrate into a landfill before a final cover has been established range up to 90% of the annual precipitation.

4. Leachate will be produced almost immediately from a landfill composed of unmilled refuse. Initially the volume produced per unit of infiltration may be small but this will continue to increase and will not stabilize until the refuse in the landfill has reached field capacity. Remson et al* (1968, p. 309) in a study in Pennsylvania determined that the field capacity of refuse was at a moisture content of 3.44 in./ft. of depth per unit surface area. The initial moisture content of the refuse used in this study was 0.46 in./ft. of depth per unit surface area. If we assume similar conditions in Ontario and that one foot of precipitation will infiltrate a landfill each year, yearly precipitation will bring approximately four feet of refuse to field capacity. Under these circumstances many landfills will be completed years before all of the refuse has reached field capacity and the maximum amount of leachate is produced.

5. Most of the annual ground-water recharge will take place in the spring and the fall and it is expected that the leachate production from a landfill will follow a similar pattern. (Note, this short-term loading should be considered in sizing leachate collection facilities).

APPENDIX C

MONITORING

There are four possible objectives to monitoring the ground and/or surface waters in the vicinity of a landfill. These objectives are:

1. To acquire data to assist in preventing or reducing the contamination of the surrounding ground and surface waters.

2. To detect contaminated water in a water supply and so prevent the consumption of this water.

3. To assign responsibility in the event that contamination occurs.

4. To provide data which can be used to evaluate the suitability of other landfill sites.

All but the first of these have been standard practice in the Ministry and need no further discussion. A few comments on the function of monitoring in preventing ground and surface water contamination may be of value however.

In recent months the Ministry has required that a contingency plan be incorporated into the design of certain landfills. Such a plan would be activated in the event the landfills do not function as anticipated and it appears that their impact on the adjacent ground or surface waters will be unacceptable. Activation of such contingency plans will depend on the results of the monitoring and both the Ministry and the Applicant should agree in advance on the critical levels of various parameters in samples obtained from selected monitoring points. Discharge standards would be set by the Ministry on a case by case basis.

In such a monitoring program it would, in most cases, be necessary to obtain evidence of dissolved solids moving from the disposal site in order to evaluate the effect that the landfill has had on the surrounding ground water and the degree to which the leachate has been attenuated. If monitoring suggests that the problems are likely to develop, remedial measures can be initiated before environmental damage becomes serious or before the refuse disposal operation has been completed, ownership has changed, or the site has been converted to another use.

The following general comments may be of value:

1. It is important to understand clearly both the construction of a monitoring point and the part of the flow system (contaminant plume) that the monitoring point samples, before it is possible to interpret data obtained from that monitoring point.

2. A simple input or recovery test should be performed on each sampling or monitoring point to determine if it is functioning properly. If the materials in which the monitoring point has been installed are fine textured, time lag (Hvorslev, 1951 p. 36) should be taken into account in interpreting water-level measurements.

3. Water levels should be measured in monitoring points before they are disturbed by cleaning and sampling. An anomalous water level should be explained or the water quality determination from that installation is suspect.

4. Monitoring points may be installed above (lysimeters) or below (well points) the top of the zone of saturation, in fine or in coarse-textured material. They can be used to measure ground-water potential or to collect ground-water samples. Installation techniques depend upon the hydrogeology of the site, the type to be installed and the purpose for which it is intended. This is a specialized field and requires experienced personnel.

5. Seasonal effects, laboratory and sampling errors should be considered when interpreting water quality analyses.

APPENDIX D

GROUND WATER MOUNDING AND LEACHATE SPRINGS

Ground-water mounds commonly develop beneath landfills, often raising ground-water levels into the refuse. They are commonly evidenced by the presence of leachate springs around the margin of a landfill where the ground-water level has risen to intersect the ground surface. The development of such mounds can be explained as follows.

Before a landfill is constructed the ground-water system at the site is at equilibrium, the water table rising and falling in response to changes in precipitation and ground-water flow into and out of the area. These fluctuations in water level reflect changes in the hydraulic gradient which are necessary to move the different amounts of water.

The implacement of a landfill disturbs this equilibrium and causes changes in the ground-water system. Both the amount of infiltrating water (through the landfill surface) and the permeability of the materials (along the sides and base of the landfill excavation) will be modified by landfilling. These changes will, in turn, cause a compensating change in the hydraulic gradient. This change in gradient is often expressed in the form of a ground-water mound (i.e. an increase in gradient).

The increase in gradient, or the ground-water mound, may be caused by:

a) an increase in the amount of the infiltration through the landfill surface; or

b) a decrease in the permeability of the materials on the sides and base of the landfill.

An increase in the amount of infiltration through the landfill surface might be caused by a decrease in runoff or in evapotranspiration from the surface of the landfill. Surface runoff from a landfill is often reduced by the development of closed depressions caused by settlement or in an attempt to control erosion. Evapotranspiration would be relatively low on landfills until a vegetative cover has been established.

A decrease in the permeability of the material on the sides and base of the landfill might be caused by mixing (i.e. decreasing sorting) and compaction of the earth materials during the construction and filling operation or by the installation of a liner. In addition, studies at the Illinois State Geological Survey (R.A. Griffen, personnel communication) indicate that the passage of leachate through earth materials tends to decrease the permeability of these materials.

Although both increased infiltration and decreased permeability probably contribute to ground-water mound development, it is suspected that decreased permeability on the sides and base is the principal cause.

It is commonly believed that when refuse in a landfill is placed below the water table, ground water will move through the refuse and produce excessive quantities of leachate. This is not always true however. Where ground-water mounding develops in a landfill, and the ground-water gradient is reversed ground-water movement will be out of rather than into the refuse and ground water which has not infiltrated through the surface of the landfill cannot contribute to leachate production.

Conditions which would inhibit the development of a ground-water mound and thereby allow the movement of ground water through a landfill which extends below the water table are:

a) the presence of a low permeability cover or some other device on the landfill to reduce infiltration,

b) the presence of materials with high permeability on the sides and base of the landfill,

c) the presence of a large horizontal component to the ground-water flow vector.

To expand somewhat upon point (c), the greater the horizontal component of the ground-water flow vector, the greater is the rise in water level beneath the landfill necessary to reverse this horizontal component of flow, thus precluding the movement of ground water from outside the landfill site into and through the refuse. This explains, in part, the prevalence of leachate springs in landfills on hillsides, where natural ground-water gradients are high.

APPENDIX E

LANDFILL GASES

Decomposition in a landfill produces a number of gases, including methane and carbon dioxide. The possible presence of these gases should always be taken into consideration when building on a landfill and in the area surrounding a landfill.

Carbon dioxide will dissolve in infiltrating water or in ground water with which it comes in contact. This gas will increase the solution of calcium carbonate in the water, and as calcium is the main constituent of hardness, the hardness of the water will also be increased. It will also decrease the pH, making the water more corrosive.

Methane will combine with air to form an explosive mixture and there have been a number of instances where explosions have been attributed to methane migrating from a landfill into enclosed areas and being ignited. Most instances in which the control of landfill gases has been undertaken have been initiated when methane was detected in basements or other structures adjacent to a landfill.

Vegetation kills are often associated with landfill gases and may be the first indication that these gases are present.

Gases migrate most easily through unsaturated, course-textured materials and therefore gas problems are most likely to develop in landfills in hydrogeologic environments where such conditions are present. The most common of these environments are upland gravel pits.

Specialized procedures for controlling landfill gases have been developed and problems associated with landfill gases have been successfully dealt with at a number of Ontario landfills (Mississauga Landfill and Kitchener-Ottawa Street Landfill). Adequate site design can prevent off-site gas problems.

APPENDIX F

LANDFILL AGE AND STABILIZATION

The length of time a landfill will remain "active" and continue to decompose and to produce leachate is difficult to predict with any certainty. There is record of a landfill less than 3 years old (Schneider, 1953, p.84) in which the refuse had decomposed to the degree that it could be used for cover material. There is also record of a landfill which continued to produce methane for more than thirty years (Eliassen, 1947, p. 757).

The moisture content of the refuse and the rate at which water moves through the landfill are probably among the major factors controlling the rate of decomposition. It is expected that minimizing the amount of water which comes in contact with the refuse would slow the rate of decomposition and reduce the rate at which contaminants are discharged from the landfill, but would extend the period over which the landfill remains biologically active and continues to produce leachate. Reducing water flow through the landfill may also allow additional time for more complete decomposition within the site and reduce the total amount (as well as the rate) of organic contaminants which will leave the site.

Conversely, it is expected that increasing the quantity of water moving through a landfill would increase the rate and total quantity of contaminants produced but reduce the time required for stabilization of the landfill.

Laboratory studies (Pohland, 1975, p. 1) have been carried out which show that the rate of decomposition in a landfill can be accelerated by the controlled recycling of the leachate through the refuse. These studies suggest that it may be possible to manage a landfill so that within a period of one or two years all or most of the readily degradable organics in the leachate will have disappeared, the pH of the leachate will have risen to 6 or 7, the COD in the leachate will have dropped to values on the order of 200 ppm, and the content of metals in the leachate will have decreased substantially. It should be noted that continued recycling without any discharge will result in the accumulation of leachate in the landfill. This procedure has not as yet been proven in the field.

Some concept of the active biological life of a landfill is necessary to any estimate of the total cost involved in its future maintenance. A simple equation for estimating the time required for landfill stabilization is as follows:

$$T = \frac{W_r \times W_{cl}}{W_l \times \frac{C_{cl}}{10^6}}$$

Where:

T = Time in years required for stabilization.
W_r = Total weight of the refuse in the landfill (lbs).
W_{cl} = Weight of the chloride ion in one pound of refuse. According to Moon, (1970, page 36) there is approximately 0.001 lb. of chloride in one pound of refuse.

W_l = Weight of leachate produced by the refuse (lbs) in one year.
C_{cl} = The average chloride ion concentration in the leachate over the life of the landfill in ppm. This is estimated to be about 200 ppm and is an arbitrary figure based on data presented in Hughes et al (1971 p. 48). To arrive at a minimum value for the stabilization time, it is suggested that the chloride ion concentration in the leachate be assumed to be 2,000 ppm - its value in relatively fresh leachate.

A similar but more sophisticated estimate of landfill age was made by Hydrology Consultants Limited, (1976) of Mississauga, Ontario, in a report prepared about a landfill in the Toronto area. This calculation uses a decay curve to take into account the high concentration of dissolved solids in landfill leachate during the early stages of decomposition and the decreasing concentration of these dissolved solids in the leachate as stabilization progresses.

Most of the data used to arrive at such estimates are based on personal judgement and are only weakly supported by either laboratory or field evidence. These estimates can be used as a rough guide to potential problems but not as a basis for firm commitments. Perhaps their major value is in bringing out the fact that a landfill continues to produce leachate and gas for tens of years and estimates of maintenance etc. should be made accordingly.